

RADAR OBSERVATION OF LARGE ATTENUATION IN CONVECTIVE STORMS: IMPLICATIONS FOR THE DROPSIZE DISTRIBUTION

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1. Introduction

Airborne meteorological radars typically operate at attenuating wavelengths. The path integrated attenuation (PIA) can be estimated using the surface reference technique (SRT) [Meneghini et al., 1992, Iguchi and Meneghini, 1994]. In this method, an initial value is determined for the radar cross section of the earth surface in a rain-free area in relatively close proximity to the rain cloud. During subsequent observations of precipitation any decrease in the observed surface cross section from the reference value is assumed to be a result of the two-way attenuation along the propagation path.

In this paper we present selected instances of high PIA observed over land by an airborne radar. The observations were taken in Brazil and Florida during TRMM (Tropical Rainfall Measurement Mission) field campaigns. We compared these observations with collocated and nearly simultaneous ground-based radar observations by an S-band radar that is not subject to significant attenuation. In this preliminary evaluation, a systematic difference in the attenuation in the two storms is attributed to a difference in the raindrop size distributions; this is supported by observations of ZDR (differential reflectivity).

2. Field observations and equipment

The TRMM field experiment was held in the southwestern Amazon from January to February 1999 and Florida from August to September 1998. A variety of instruments were deployed during the field campaigns. Here we give a brief description of relevant instruments.

The NASA ER-2 Doppler radar (EDOP) mounted on ER-2 aircraft operates at the 3-cm wavelength and has two fixed antennas, one pointing at nadir and the second pointing approximately 33° ahead of nadir. The beam width of the antennas is 3° which defines a nadir footprint at the surface of 1 km. The ER-2 ground speed is nominally 210 ms⁻¹ and the integration period used by the data system is 0.5 s. These two values imply that an estimate of the surface cross-section is obtained every 100 m along the flight track and so 10 samples are obtained during the travel of one beam width. The range resolution is 37.5 meters. Additional details of the radar and processing are described by Heymsfield et al. (1996). NCAR S-Pol (S-band Polarization) is a ground-based radar operated at 10 cm wavelength. The beam width of S-Pol antenna is 0.91° and range resolution is 150 meters. (<http://www.atd.ucar.edu>)

3. Observations

Fig. 1a shows the reflectivity observed by EDOP forward antenna from a deep convective storm on 10 February 1999 in Brazil. The 40 dB reflectivity reaches up to 8 km in height and the maximum reflectivity is about 45 dBZ. Fig. 1b shows PIA estimated from the surface reflectivity measured along the forward path (solid line). A maximum PIA of 30 dB occurred around 19 km distance. PIA from nadir measurement is not used because it is subject to large errors due to the high variability of the surface return over land at nadir incidence.

For this case, reflectivity data were obtained from the S-Pol radar located about 60 km from the storm and the volume scan nearest in time to the over-flight was interpolated to a grid coincident with the vertical plane mapped out by the EDOP radar. PIA was then estimated from the S-pol data using an empirical relation between the specific attenuation (k) and reflectivity (Z). The path of the

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integration was along the path of the EDOP forward beam. The maximum PIA derived from the S-Pol reflectivity (dashed line in Figure 1b) shows a maximum of 13 dB which is less than half of that observed from the EDOP.

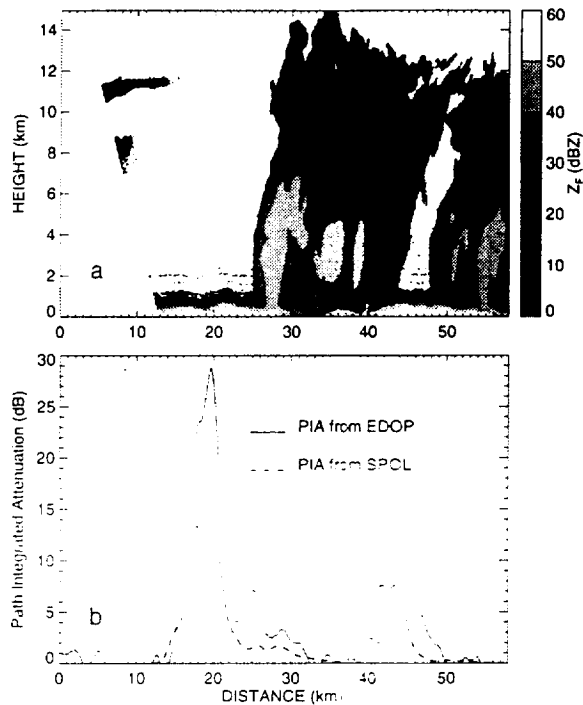


Fig. 1 a) Reflectivity observed by EDOP on February 10, 1999 during 1811-1819 UT in Brazil. b) PIA estimated by EDOP using surface reflectivity (solid line) and using an empirical relation between the specific attenuation and reflectivity obtained by SPOL (dashed line)

Fig. 2 is similar to Fig. 1 but the observation was taken in Florida on 15 August, 1998. The storm in Florida is more intense; The 40 dB reflectivity reaches up to 15 km (Fig. 2a) and the maximum reflectivity observed by EDOP is 55 dBZ. The maximum PIA observed by EDOP (solid line in Fig. 2b) is about 25 dB which is lower than the case in Brazil. The maximum PIA calculated from k-Z (specific attenuation and reflectivity) relation using reflectivity from S_Pol (dashed line in Fig. 2b) is about 15 dB. The actual value would be about 18 dB if the highest elevation scan topped the storm.

How do we explain the large PIA observed in Brazil? Why is there a difference in PIA derived from k-Z relation and from the SRT? There are several possibilities: a) a non-typical raindrop size distribution, b) wetted ice particles such as snow

aggregates, graupel, or hail, c) large non-spherical particles, d) error in the measurement of the surface return. In this paper, we will limit our scope on a) and discuss others briefly.

For the possibility of hail we examined reflectivity and ZDR from S_Pol. In general, ZDR is a measure of mean drop size and is positive

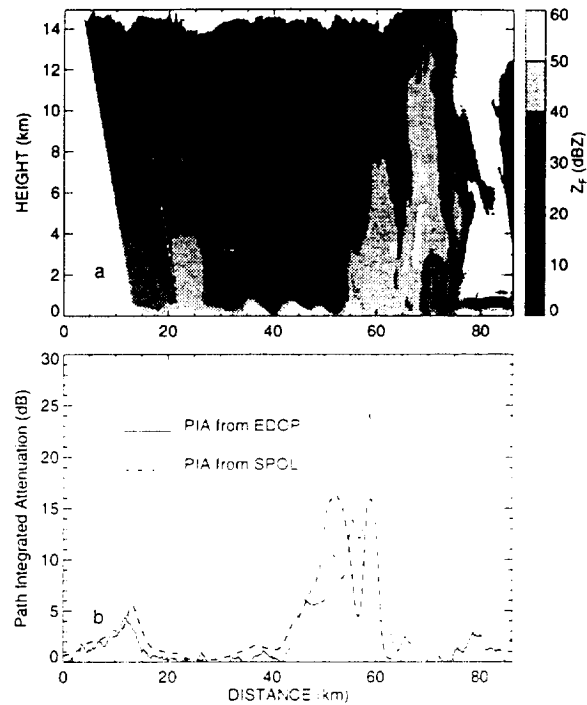


Fig. 2 Same as Fig. 1 but the observation is on August 15, 1998 during 2223-2230 in Florida.

for rain and near zero for hails. Also the reflectivity increases substantially with the presence of hail because the scattering cross section of hails are much larger than that of raindrops. Below the melting level, ZDR is about 1dB for the Brazil case, and 2 dB for the Florida case. The maximum reflectivity observed in the Brazil storm was 52 dBZ. Therefore significant hail is unlikely in the Brazil storm. The maximum reflectivities in the Florida storm exceeded 55 dBZ which means that hail was likely in that storm. Below the freezing level, where most of the attenuation occurs, any hail is likely to be wet due to melting and /or because of collisions with raindrops. The accumulation of water around an ice particle can stabilize it during fall preventing the tendency of the dry particle to tumble. That wet particle is also likely to have an ellipsoidal shape similar to large raindrops because of the tendency for the melted

water to collect around the middle part of the particle as it is swept around the particle by the airflow. This can explain the high ZDR in the Florida storm despite the presence of hail. However, the wet ice particle is likely to produce large attenuation which conflicts with the lower attenuation observed in the Florida storm. The role of ice particles as a possible factor in explaining the observed differences between the two storms needs to be further examined through analysis of other polarimetric variables, vertical air velocities and other features of the storms. We propose to make such a study in the future.

The errors in PIA estimated from surface return are less than 2 dB since the variability in the surface return over the land at large incidence angle is less than 2 dB (Tian et al., 1999). It should be emphasized that the absolute value of the surface echo is not critical for PIA since it is a difference of the surface return in adjacent rain-free and rain area. What is important, however, is that the surface echo does not change as a consequence of wetting from the rain since any changes in the surface cross-section are assumed to be a result of attenuation along the propagation path. In the cases studied so far with the EDOP radar, no significant change in the cross-section has been observed at the transition between rainy and clear conditions for non-nadir incidence.

Now we shall interpret the difference in PIA in terms of differences in the DSDs in the two storms.

4. Discussion

a) Theory

Attenuation greater than that given by empirical equation could be due to unusual rain drop size distribution, namely, predominately small drops (Tian and Srivastava, 1996). For an exponential drop size distribution,

$$N(D) = N_0 \exp(-\Lambda D) \quad (1)$$

where $N(D)dD$ is the number of drops of diameter between D and $D+dD$ per unit volume. and the slope Λ can be written as

$$\Lambda = C_1/D_0 \quad (2)$$

where D_0 is the median drop diameter and $C_1 = 3.67$ if the maximum diameter of the drop $D_{max} \rightarrow \infty$. The reflectivity factor is given by

$$Z = \int_0^\infty N(D) D^6 dD = 720 N_0 / \Lambda^7 \quad (3)$$

Now suppose the extinction cross-section of a drop of diameter D is given by $Q_{ex} = CD^n$, where C and n are parameters depending on the refractive index of the drop and wavelength of the radar (Atlas and Ulbrich, 1974). Then the specific attenuation

$$k = \int_0^\infty N(D) Q_{ex}(D) dD = C_2 N_0 / \Lambda^{n+1} \quad (4)$$

where C_2 is a numerical constant. Eliminate N_0 between (3) and (4), we have

$$k = C_3 N_0^{(6-n)/7} Z^{(n+1)/7} \quad (5)$$

Where C_3 is a numerical constant. Suppose we have two exponential distributions with intercepts N_0 and $N_{(n)}$, such that they both give the same Z . Then we have

$$N_0 / \Lambda_0^7 = N_{(n)} / \Lambda_{(n)}^7 \quad (6)$$

where Λ_0 and $\Lambda_{(n)}$ are slopes for the two distributions. From the eq.(3), the ratio of k 's (k_0 and $k_{(n)}$) for the two distribution will then be

$$k_0 / k_{(n)} = (N_0 / N_{(n)})^{(6-n)/7} \quad (7)$$

From (2) and (6), the ratio of the median volume diameter for the two distribution will be

$$D_0 / D_{(n)} = (N_{(n)} / N_0)^{1/7} \quad (8)$$

From (7) and (8) we see that distribution with higher N_0 will have higher k and smaller median volume diameter. As an example, for the same Z , if $k_0 / k_{(n)} = 2$ then from eq. (7), assuming $n = 4.5$, we have $N_0 / N_{(n)} = 25.5$ and $D_0 / D_{(n)} = 0.63$. Therefore, the first distribution which has twice the attenuation has an intercept which is 26 times the intercept of the 2nd distribution; the first distribution also has a median volume diameter which is smaller; it is 0.63 times the median volume drop diameter of the 2nd distribution.

b) Observations

There were no coincident or near-coincident observations of DSD taken for the two flight lines due to the strong intensity of the storms. However, average drop size distributions from the ground-based distrometers suggest more smaller drops and less bigger drops in Brazil compared to Florida (personal communication, Tokay, 2000). The observed ZDR difference between the two cases also implies a smaller median volume drop

diameter in the Brazil storm if we assume that the reflectivity is dominated by raindrops in both storms.

Fig. 3 shows the frequency of ZDR for intervals of 4 dBZ and 0.5 dB in reflectivity and ZDR respectively. The data was limited to the area where the large PIA occurred and below the melting level. It shows a systematic difference in ZDR for given reflectivity between the Brazil (Fig. 3a) and the Florida (Fig. 3b) flight lines. For example, for given reflectivity of about 40 dBZ, there is a greater occurrence of ZDR of 1 dB in Brazil and 2 dB in Florida, corresponding to a median drop diameter of 1 mm and 1.8 mm respectively.

5. Future Work

In this paper, we suggest that the observed large PIA observed in Brazil is due to a substantial large number of smaller drops based on observation of DSD and ZDR. In the future we will (1) examine further the possible role of ice in the X-band attenuation using other polarization measurements from S-Pol; (2) conduct a more detailed comparison between the S-band (S-Pol) and X-band (EDOP) reflectivities, including vertical profiles; (3) Finally, we will try to explain why the drop sizes distribution may be different in the two places and study the possible role of ice particles and wet ice particles in explaining the differences in attenuation.

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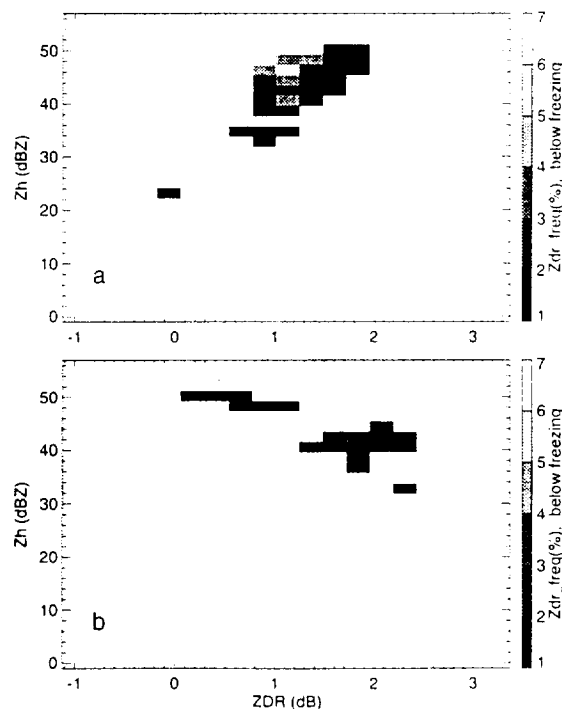


Fig. 3 Frequency occurrence of ZDR for given interval of reflectivity and ZDR observed by S-Pol in the region where high PIA is observed for the case shown in Fig. 1a (a) and Fig. 2b. (b).